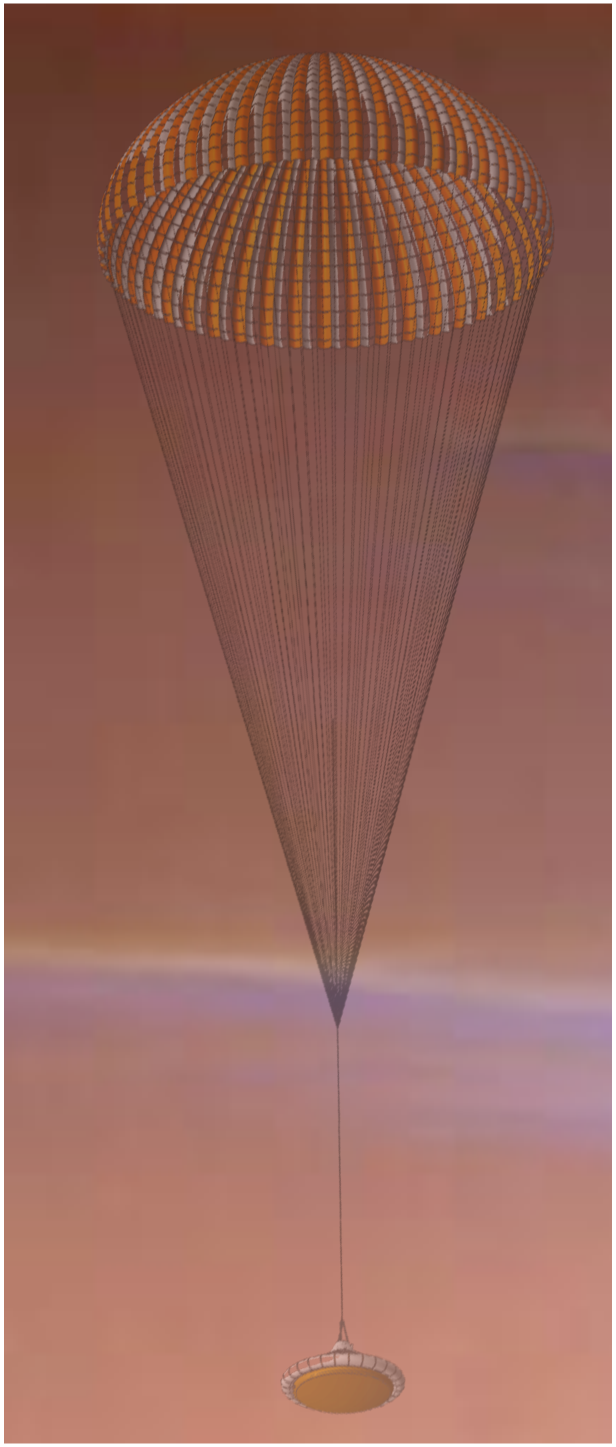

LDSD

Low Density Supersonic Decelerator Technology Demonstration Mission

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June 9, 2011

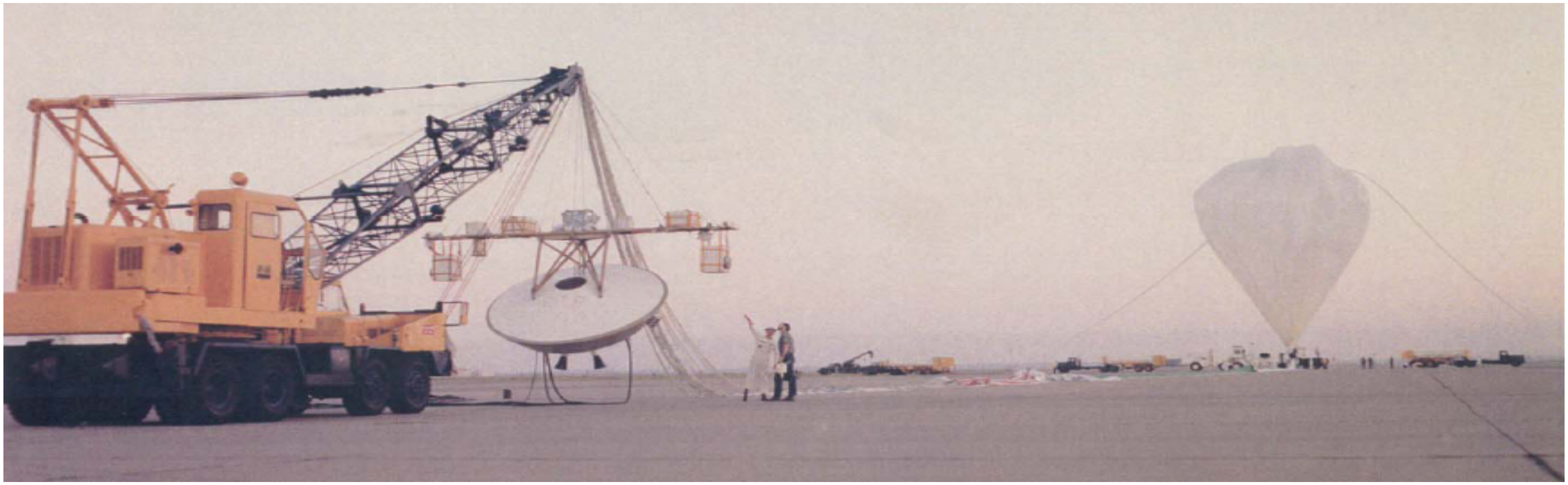
8th International Planetary Probe Workshop

Material from LDSD team, including:

Tom Rivellini, Adam Steltzner, Brant Cook, Lou Giersch, Mike Meacham

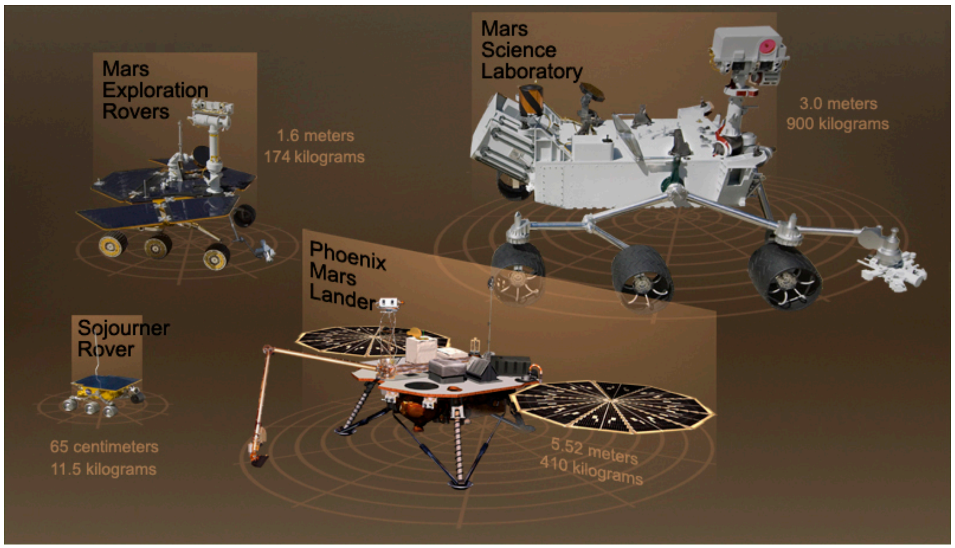
Abstract

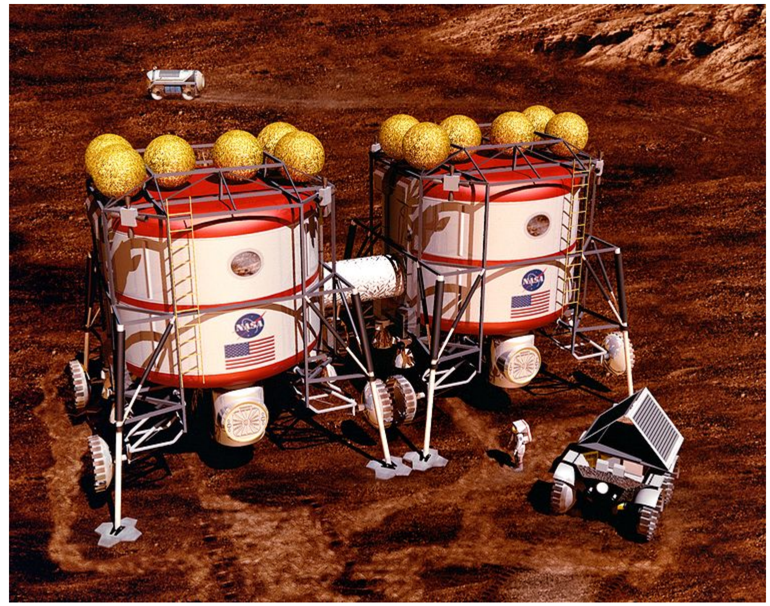
- *The heady days of sticking a rocket under your gizmo just to see if it works are coming back.* In the summer of 1972, the Viking Project conducted four high-altitude tests in Earth's atmosphere of the supersonic parachute design to be used for landing on Mars. We've been stuck with that design ever since. In late 2013 and early 2014, a series of balloon-launched, rocket-propelled tests of the next generation of supersonic decelerators will culminate the development program of new descent technologies to be used on future Mars landers. A Mach 3.5 inflatable decelerator and a Mach 2 ringsail parachute will team to create a low-density supersonic decelerator system for high ballistic coefficient entry systems at Mars.



Problem

- As Mars landers grow, ballistic coefficient (β) goes up (square-cube law problem) — currently at ~1000 kg useful landed mass for MSL
- Launch vehicle fairing size not going up, lift / drag not going up



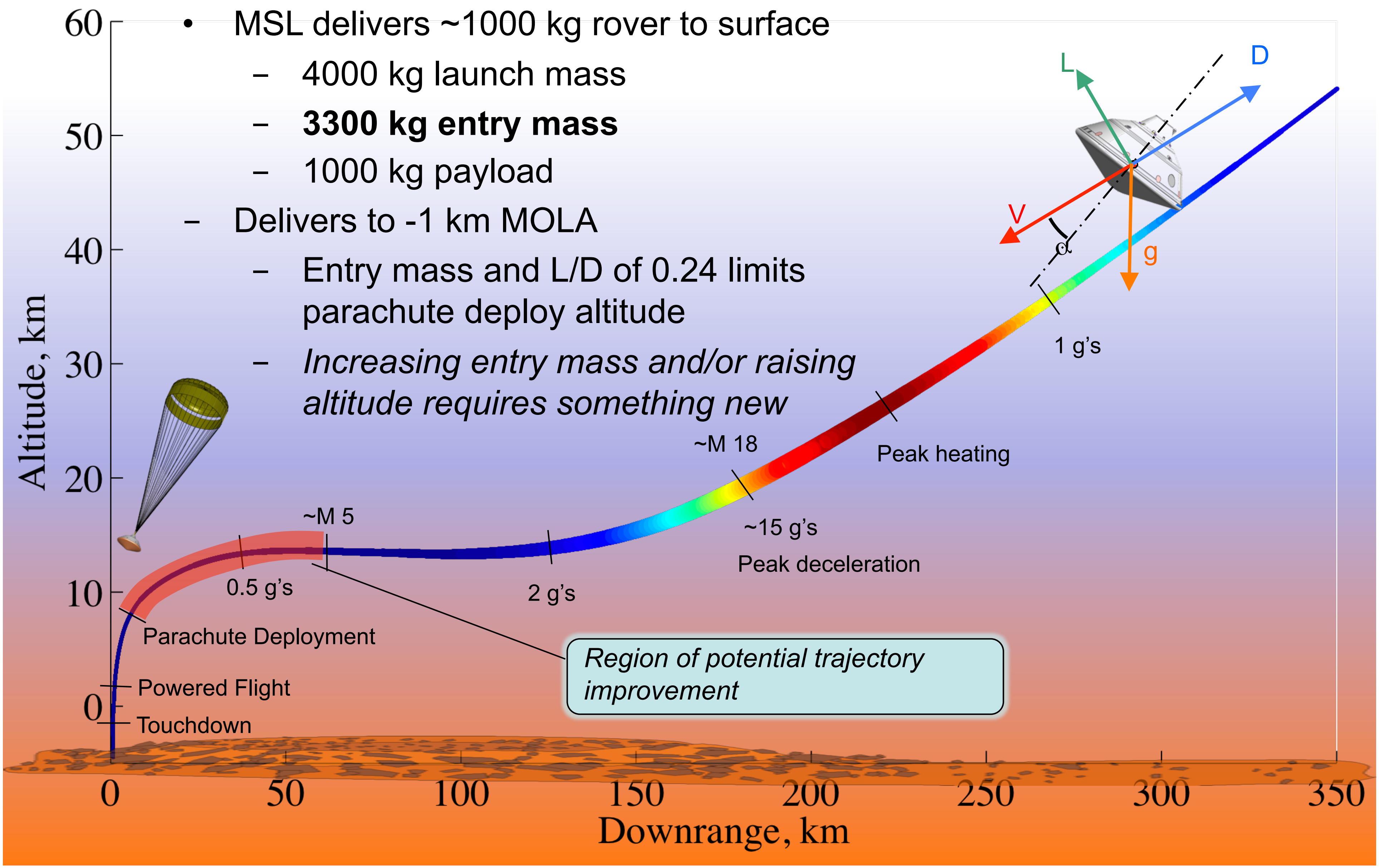


- Need to deploy a parachute at Mach ~2, but …
- *As β keeps going up, eventually we hit the ground at Mach > 2*
- Need to begin the scale-up to crewed Mars landers ~50,000 kg (!)
- What can we do before these things hit the ground?

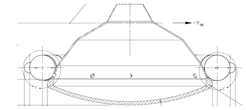
MSL Problem Area

Supersonic Inflatable Aerodynamic Decelerator

- MSL delivers ~1000 kg rover to surface
  - 4000 kg launch mass
  - **3300 kg entry mass**
  - 1000 kg payload
- Delivers to -1 km MOLA
  - Entry mass and L/D of 0.24 limits parachute deploy altitude
  - *Increasing entry mass and/or raising altitude requires something new*



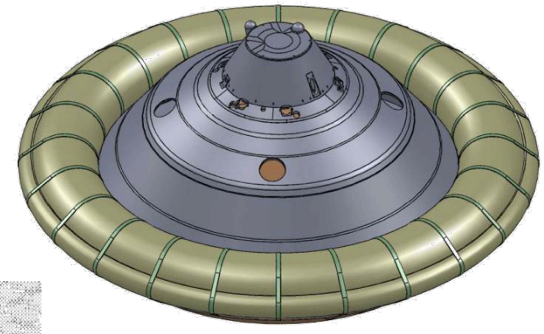
Solution Trade Space

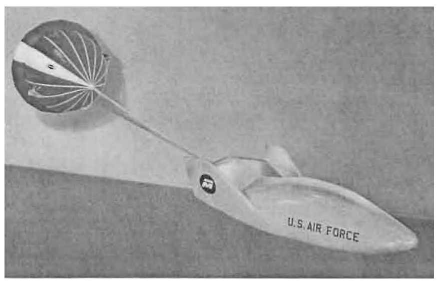


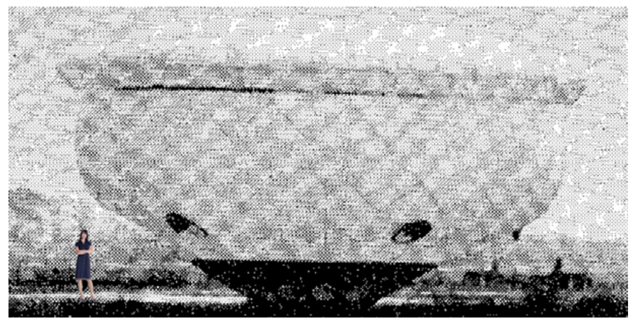
- Lower β or increase L/D (pull up)?
  1. β ~ mass / area, so increase the area (recall mass is going up)
  2. ~~Develop new entry vehicle shape and hypersonic maneuvering capability~~
- This effort addresses Door #1
  – Potentially some other technology development could work on Door #2
- When to increase the area?
  1. ~~Increase the area before launch~~ (new launch vehicle development)
  2. ~~Increase the area before entry~~ (high heating, but see HIAD talk next)
  3. Increase the area just in time, before you hit the ground, ~ Mach 3 to 5 (easiest)
- How to increase the area?
  1. Deployed fabric structure (low mass, low cost)
  2. ~~Deployed rigid structure~~ (higher mass, higher cost)
- What is the fabric structure?
  1. ~~Parachute~~ (poor drag at high Mach, inflation complex and problematic)
  2. *Inflatable aerodynamic decelerator* (good drag at high Mach, simple)

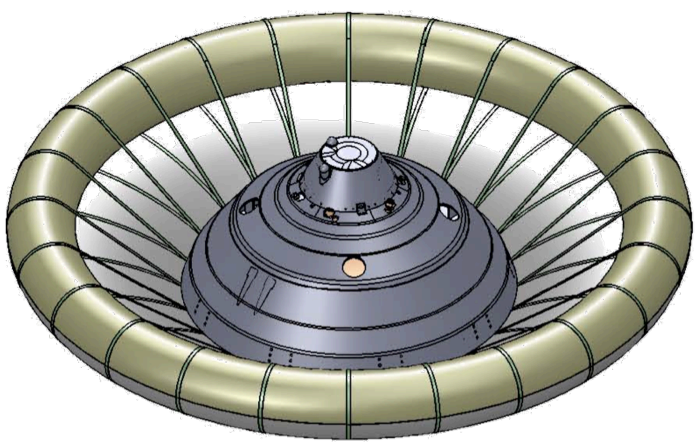
Supersonic Inflatable Aerodynamic Decelerators

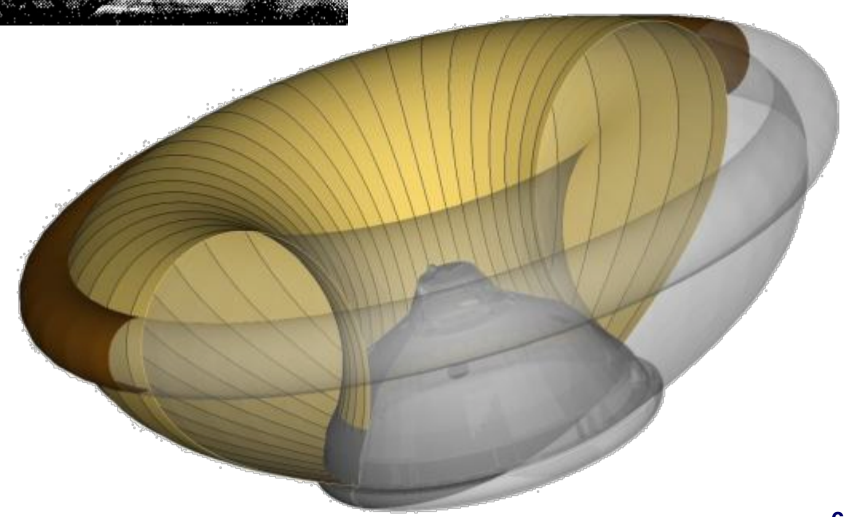
- Various kinds of Inflatable Aerodynamic Decelerators were studied and tested in the 1960's
- After Viking, IAD research effectively ceased
- Now that we've tapped out the Viking technology, we are revisiting IADs



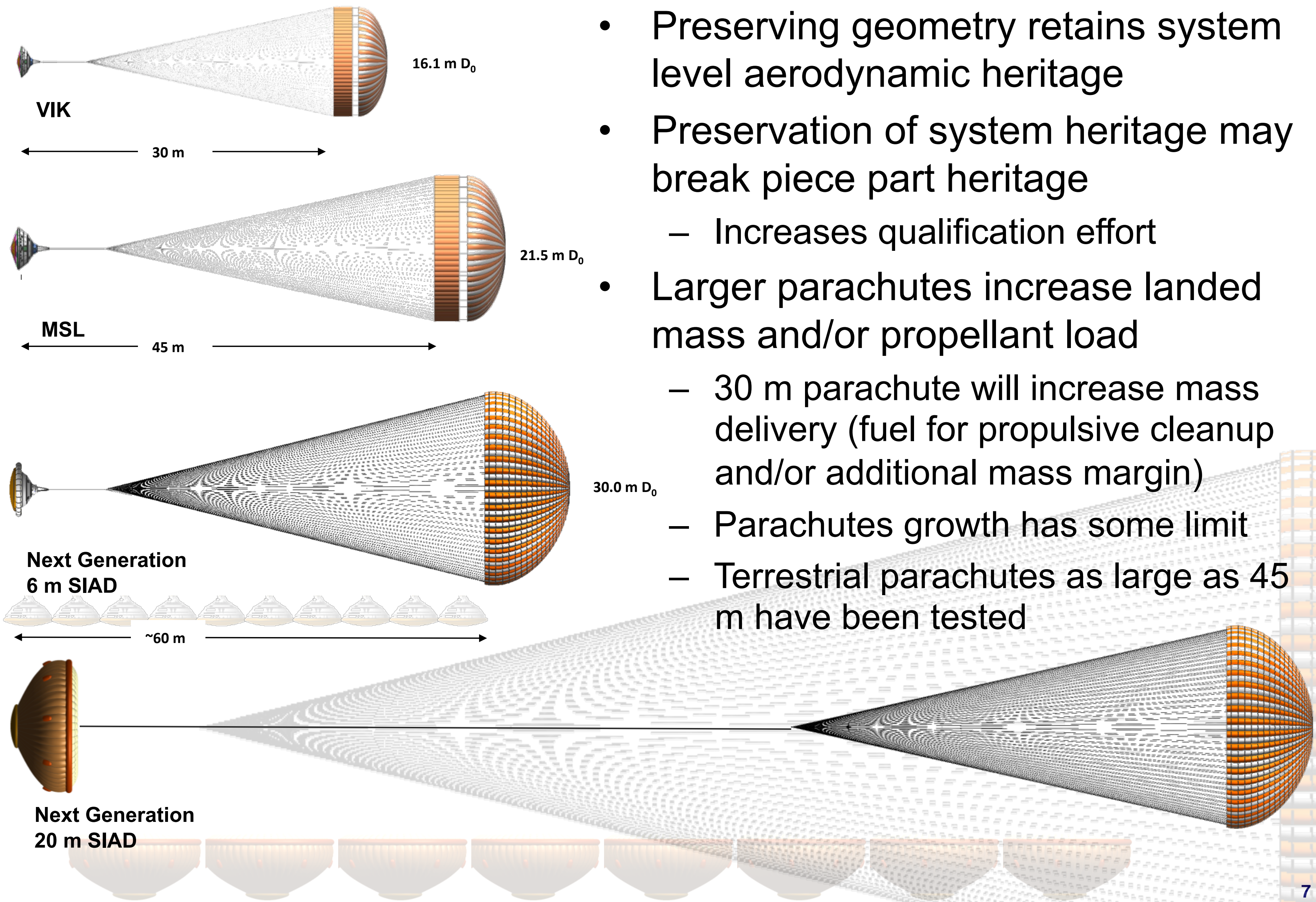








Parachute / Vehicle Diameter Heritage

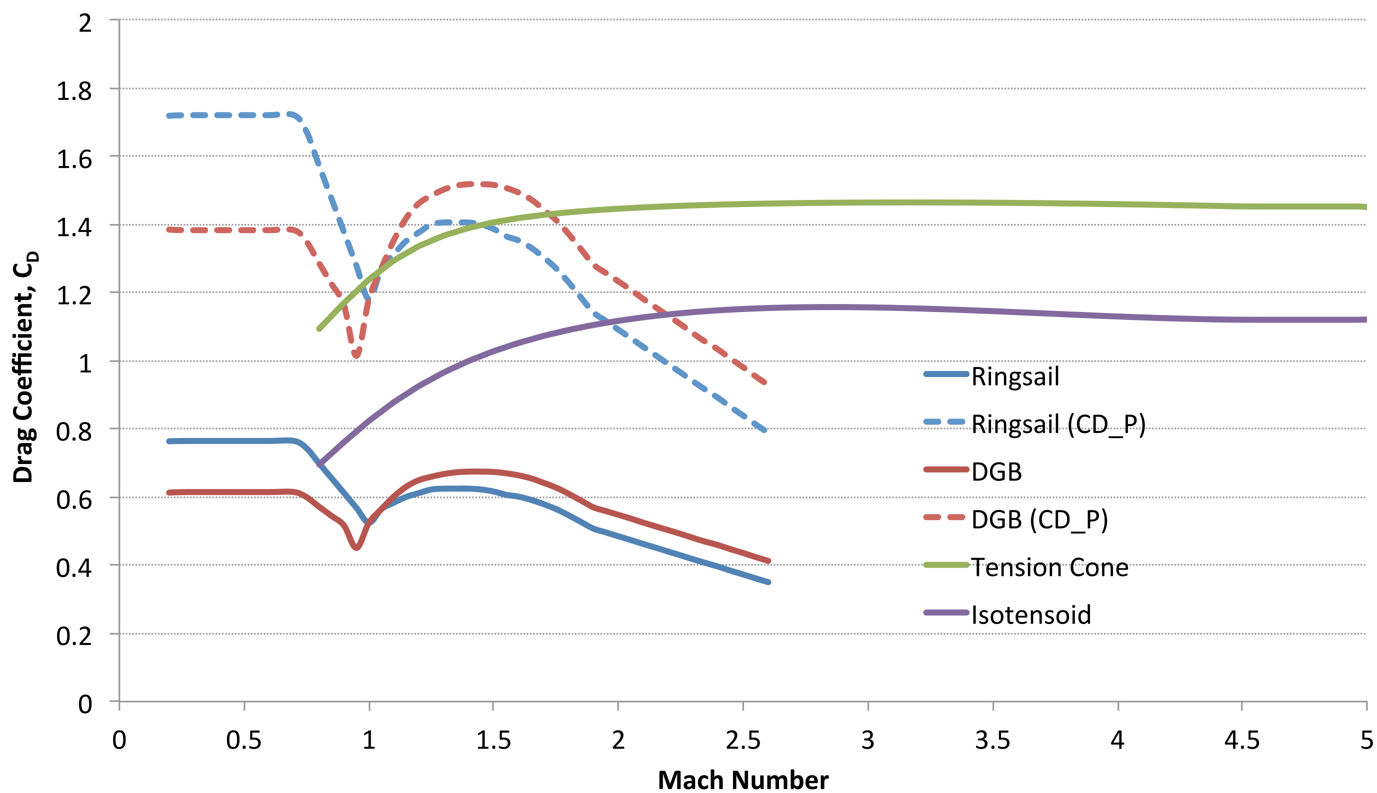


- Preserving geometry retains system level aerodynamic heritage
- Preservation of system heritage may break piece part heritage
  - Increases qualification effort
- Larger parachutes increase landed mass and/or propellant load
  - 30 m parachute will increase mass delivery (fuel for propulsive cleanup and/or additional mass margin)
  - Parachutes growth has some limit
  - Terrestrial parachutes as large as 45 m have been tested

SIAD and Parachute Drag vs. Mach

Supersonic Inflatable Aerodynamic Decelerator

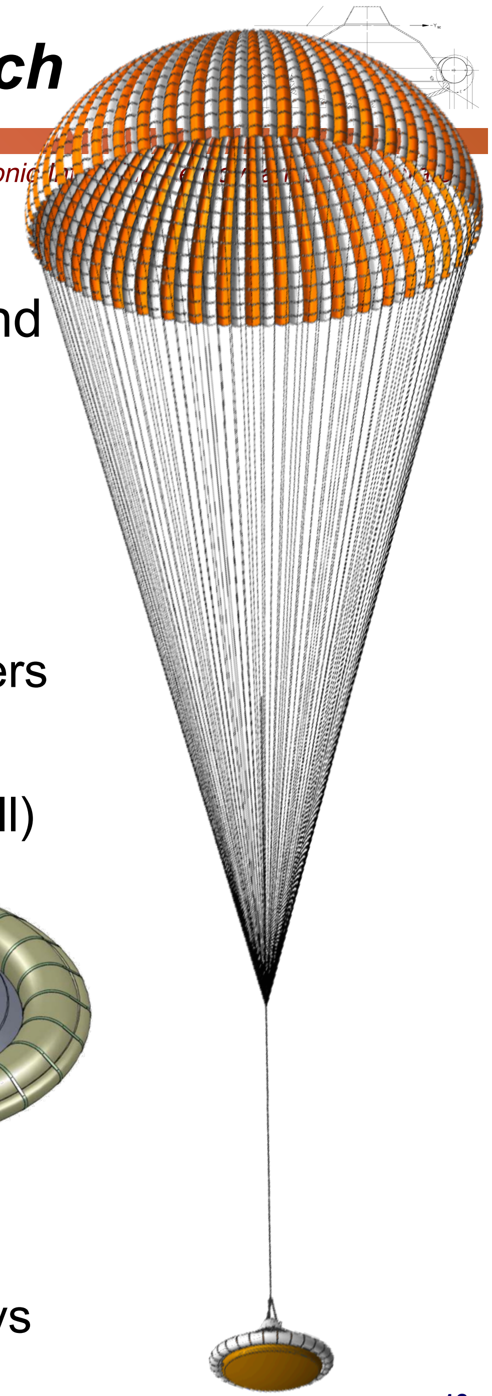
- SIADs and parachute complement each other well
  - Just as SIAD drag is starting to fall off in Mach, parachute drag is up
- Drag fall-off makes a subsonic SIAD impractical
  - Might like to get to subsonic before parachute deploy, or eliminate parachute completely — however the SIAD becomes impractically large



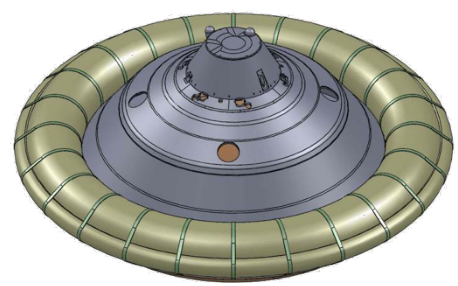
Low-Density Supersonic Decelerator System

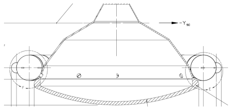
- SIAD needs to be paired with a larger parachute
  - Preserve diameter ratio heritage to avoid new wake effects region
  - Larger parachute required in order to cash in on SIAD benefits
    - Greater entry mass converted to greater terminal descent propellant mass and/or greater payload mass
    - Altitude provides timeline for larger parachute deploy
- Viking DGB heritage has been extended to its limit by MSL
  - Viking did one supersonic test of a 19.7 m DGB
  - MSL is using a 21.5 m DGB
- A ringsail configuration provides improved performance over DGB
  - More mass-efficient drag
  - Greater stability
  - Improved inflation behavior (but to be demonstrated supersonically)
- LDSD will develop and test both a SIAD and a new supersonic ringsail parachute

SIAD and Parachute Size and Deploy Mach



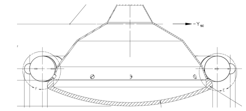
- Application trade study performed covering a wide range of SIAD and parachute sizes, entry masses, and altitudes
- Targeted improvements:
  - Entry mass 3300 kg to *4200 kg* (max for Atlas V 551)
  - Landed altitude from -1 km MOLA to *+2 km MOLA*
  - Increased timeline for SIAD and parachute range triggers
- SIAD
  - *6 m* diameter (63% increased area over 4.7 m aeroshell)
  - *Mach 3.5* deploy
- Ringsail Parachute
  - *30 m* D0
  - *Mach 2* deploy
- Extended improvements:
  - Entry mass to 5825 kg (Delta IVH max), same altitude
  - *9 m* diameter SIAD, same size parachute, same deploys





Have to Fly Them

- The qualification of soft-goods deployables requires testing of the devices at *full-scale* in a *relevant environment*
  - The motion of the soft-goods at very small scales is critical to the overall behavior of the system, making simulation impractical



SIAD Testing

Supersonic Inflatable Aerodynamic Decelerator

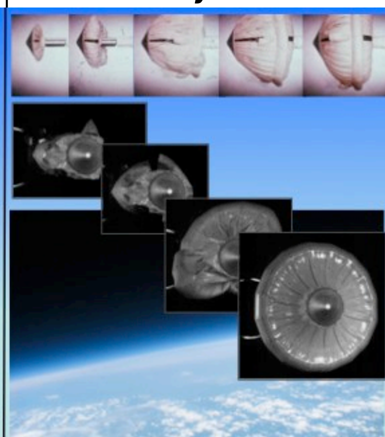
Phase 1: Initial Deployment & Inflation

Parameters/Components of Interest
Cover Panel System release
Cover Panel System interaction with SIAD
SIAD packing methodology
Gas Generator performance

Relevant Test Environment
Static Pressure
Dynamic Pressure

Method of Qualification
GG infl. @ pressure & temp.
GG infl. @ Q

Phase 2: Inflation Dynamics

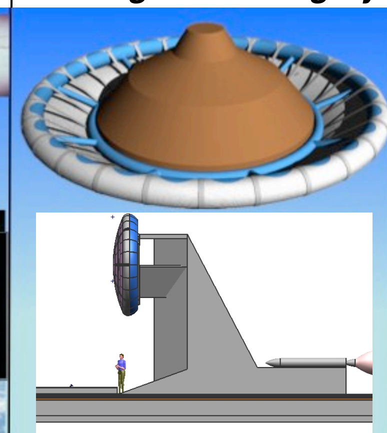


Parameters/Components of Interest
SIAD inflation dynamics
CPS behavior
Vehicle dynamics

Relevant Test Environment
Mach Number
Static & Dynamic Pressure

Method of Qualification
IAD deployment in a relevant Mach-Q flowfield, while attached to a relevant blunt body capsule.

Phase 3: Deployed Strength and Integrity



Parameters/Components of Interest
Qualification Load on IAD
IAD Inflated shape

Relevant Test Environment
Dynamic Pressure

Method of Qualification
Aerodynamic loading of SIAD to test load.

Phase 4: Supersonic Performance

Parameters/Components of Interest
IAD Inflated shape
Static Aero coefficients
Dynamic Aero coefficients
Stiffness effects

Relevant Test Environment
Mach Number
Dynamic Pressure
Non dimensional parameters

Method of Qualification
Supersonic IAD flights closely coupled with CFD analysis and subscale supersonic testing

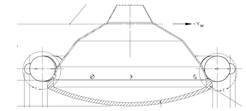
Phase 5: Subsonic Performance

Parameters/Components of Interest
IAD Inflated Shape
Parachute configuration
Static Aero coefficients
Dynamic Aero coefficients

Relevant Test Environment
Mach number
Dynamic Pressure

Method of Qualification
Subsonic flight of IAD

Parachute Testing



Supersonic Inflatable Aerodynamic Decelerator

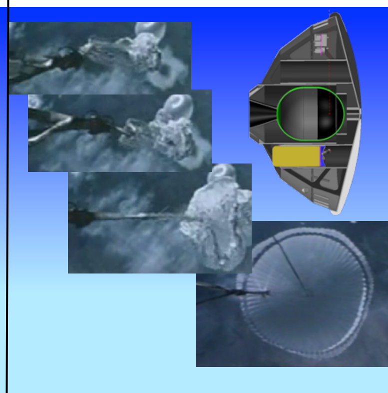
Phase 1: Parachute Mortar Deployment

Parameters/Components of Interest
Deploy bag design
Line stretch mechanics
Packing methodology
Bag strip mechanics
Deploy bag retention

Relevant Test Environment
Mortar ejection velocity

Method of Qualification
Mortar ejection

Phase 2: Initial Inflation of Parachute

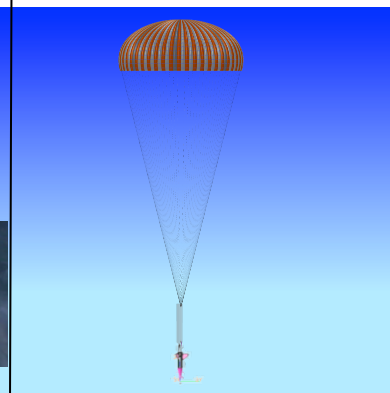


Parameters/Components of Interest
Canopy inflation dynamics
Parachute design
Flow field

Relevant Test Environment
Mach Number
Flow Velocity
Parachute Design
Wake Structure

Method of Qualification
High Altitude supersonic parachute deployments.

Phase 3: Initial Inflation Strength

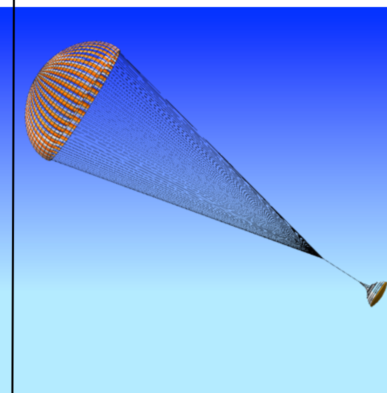


Parameters/Components of Interest
Flight Limit Load on Parachute (81k#)

Relevant Test Environment
Dynamic Pressure

Method of Qualification
High Altitude/High velocity parachute deployment.

Phase 4: Supersonic Performance

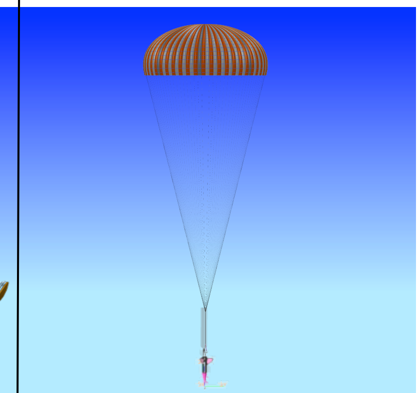


Parameters/Components of Interest
Parachute configuration
Drag coefficients
Mach efficiency curve
Stability coefficients
Area oscillation

Relevant Test Environment
Mach Number
Flow Velocity
Parachute Design
Wake Structure

Method of Qualification
High Altitude supersonic parachute flight.

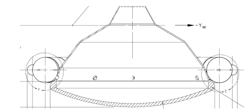
Phase 5: Subsonic Performance



Parameters/Components of Interest
Parachute configuration
Drag coefficients
Mach efficiency curve
Stability coefficients

Relevant Test Environment
Flow Velocity
Parachute Design
Wake Structure

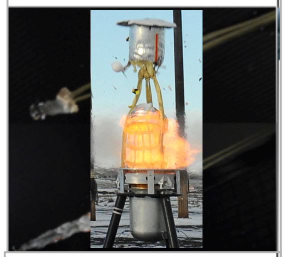
Method of Qualification
High Altitude subsonic parachute flight.



Test Types

Supersonic Inflatable Aerodynamic Decelerator

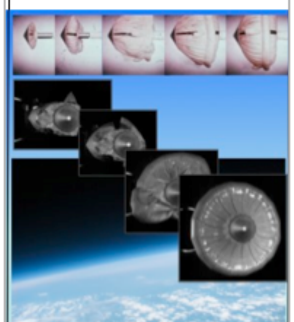
Phase 1: Parachute Mortar Deployment



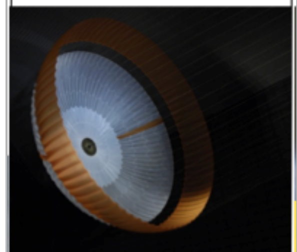
Initial Deployment & Inflation

Phase 2: Initial Inflation of Parachute

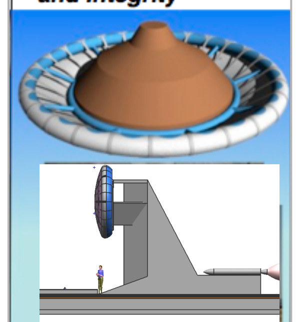
Inflation Dynamics



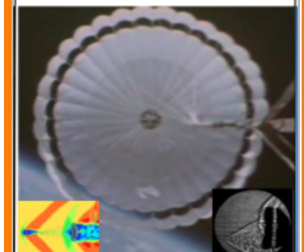
Phase 3: Initial Inflation Strength



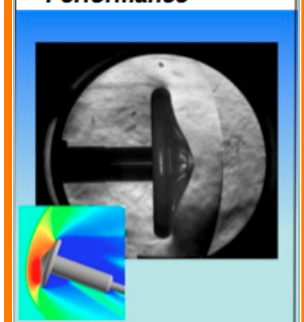
Deployed Strength and Integrity



Phase 4: Supersonic Performance



Supersonic Performance



Phase 5: Subsonic Performance

Subsonic Performance

Design Verification

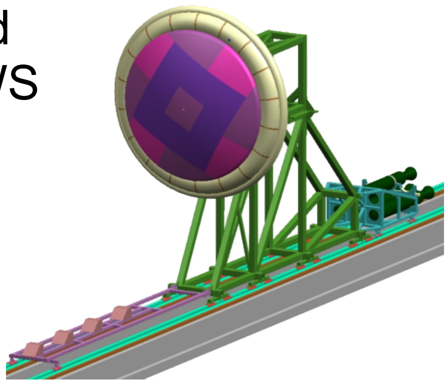
Full scale hardware testing to verify design functionality & integrity

Flight Dynamics

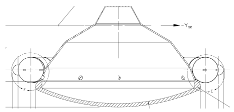
Supersonic and subsonic flight testing to verify flight dynamics and aerodynamic performance

Design Verification Tests

- Design Verification Tests (low cost, repeated by infusing project)
  - Dynamic pressure but *not* Mach is replicated to test the strength and operation of the devices
    - Allows over-testing of strength which is not feasible for at-Mach testing
    - Lower cost tests to assure working devices before at-Mach testing
  - Parachute dropped from high-altitude balloon
  - SIAD on rocket sled at China Lake NAWS

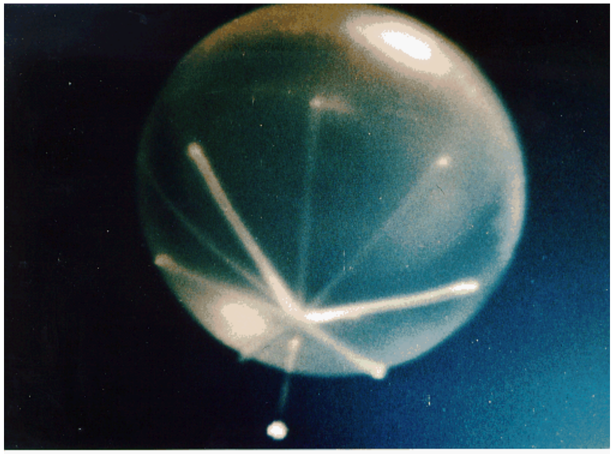


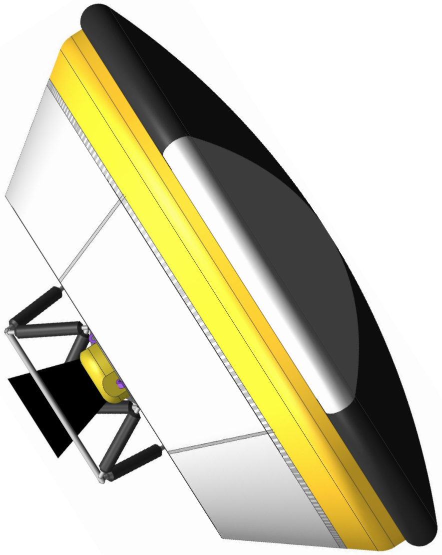
  - SIAD low pressure inflation testing
    - Rocket sled at ground uses higher-pressure inflation system
    - Test low-pressure SIAD inflation and deployment at Plum Brook

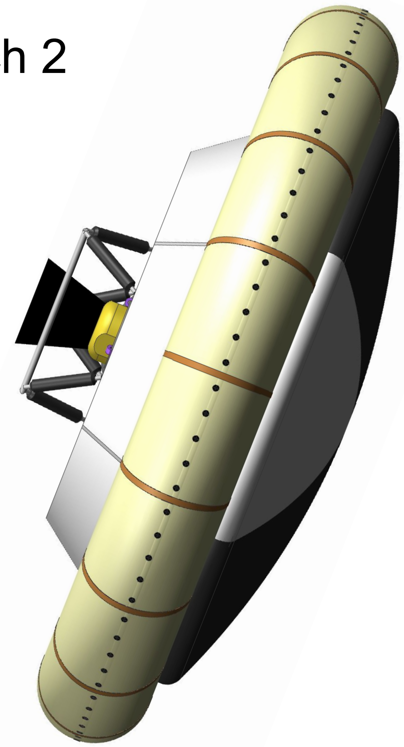


Flight Dynamics Tests

- Viking-style balloon drop (high cost, *not* repeated by infusing project)
  - Full-scale (4.7 m aeroshell) test vehicle dropped from high-altitude balloon
  - Solid-rocket motor in test vehicle accelerate to Mach 4 (spun for stability, then despun)
  - SIAD deployed at Mach 3.5
  - Parachute deployed at Mach 2

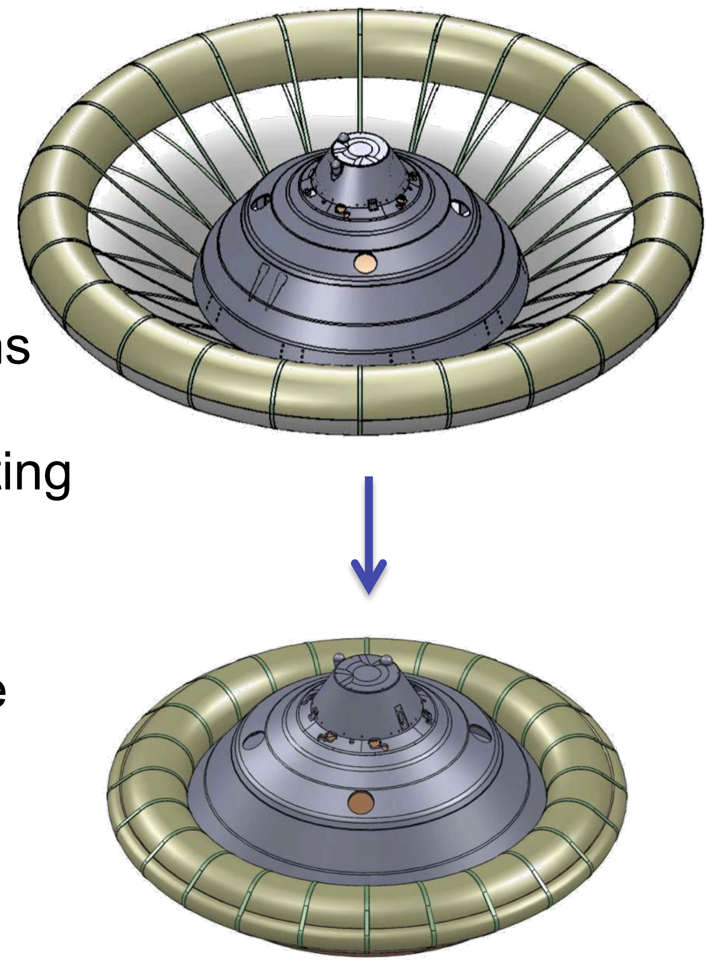






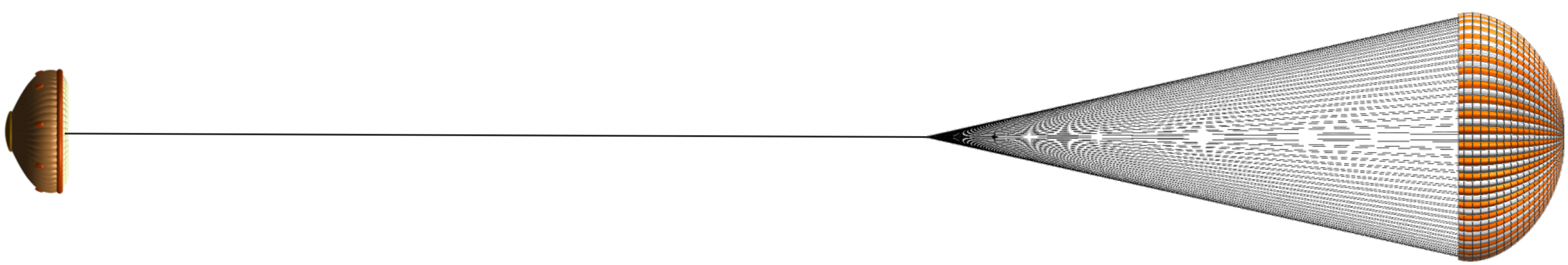
Extensibility 1: SIAD Rigidity Hypothesis

- 6 m SIAD size results in a “degenerate” tension cone — the cone part goes away
- Left with an “attached torus” configuration
- At sufficient pressure, an attached torus should behave like a *rigid structure*
- If it does, then new rigid SIAD configurations could be developed and dynamic behavior determined in lower cost ballistic range testing
- This would allow greater extensibility of the LDSD developments to new designs
- LDSD will test the rigidity hypothesis for the attached torus configuration



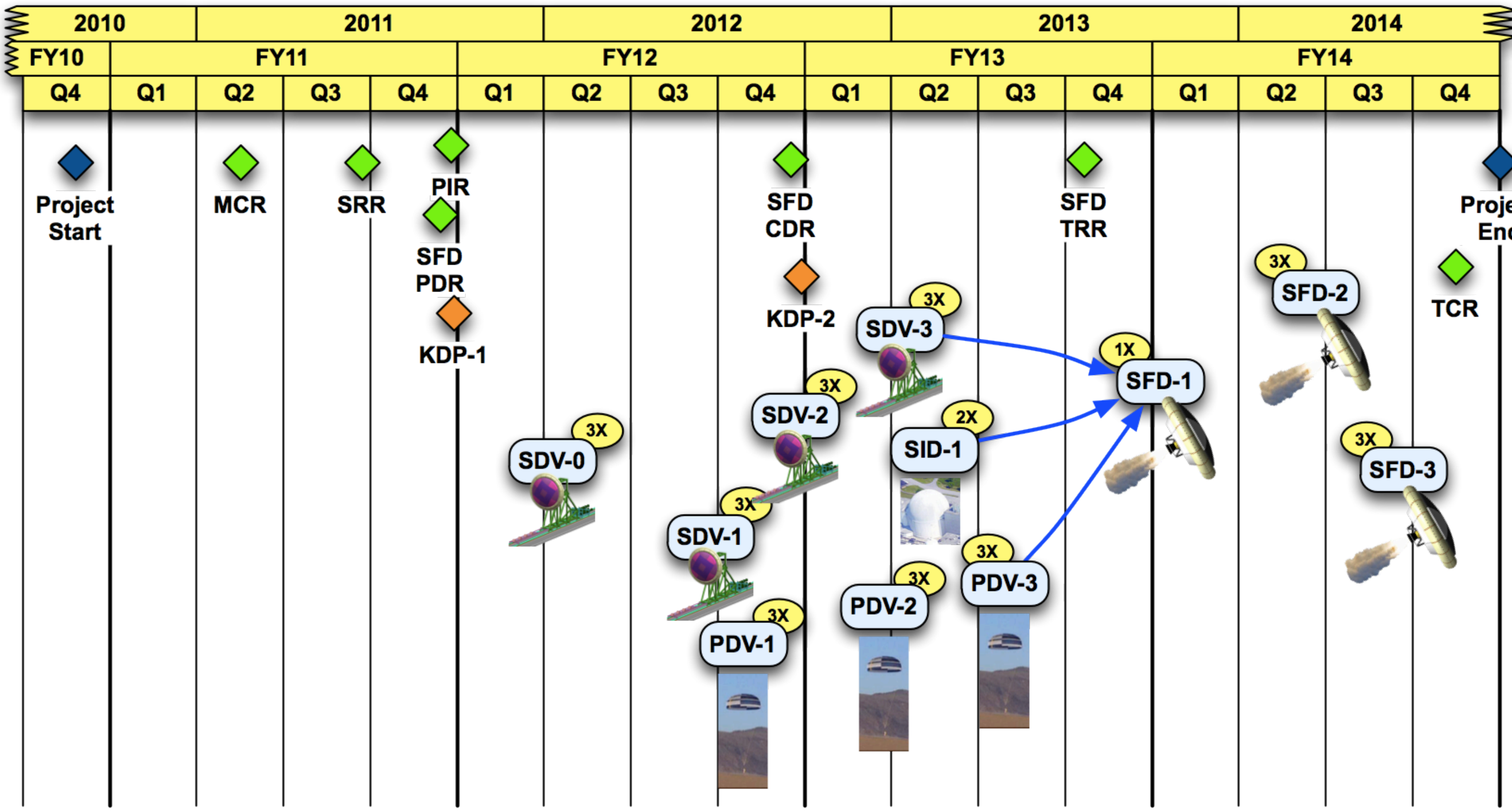
Extensibility 2: Breaking Diameter Ratio Heritage

- LDSD also plans to test configurations with larger ~9m SIADs
  - But *not* with a larger parachute, so not preserving diameter ratio
- Prepare for very large Mars landers (Delta IVH-class)
- Explore low ratios of parachute to SIAD diameter and wake effects
- Explore non-rigid SIAD configurations
- Provide data for future CFD and FSI work on these systems
  - Some CFD and FSI work will be done as part of the LDSD project in order to inform the measurements strategy



LDSD Testing Timeline

Supersonic Inflatable Aerodynamic Decelerator



LDSD Status

- LDSD will complete its formulation phase in October
  - Will enter implementation in FY12
- SIAD development
  - Conducted three industry studies on SIAD configurations and construction
  - Awarded contract for SIAD fabrication (ILC Dover), kickoff in two weeks
- Test development
  - Rocket sled fabrication will begin next month
  - Preliminary design approaches for supersonic flight testing complete
- Have been working to $12M funding through FY11
- Total estimate LDSD project cost: $160M
- LDSD is a line item in the President's FY12 budget submission
  - Total run-out of $148M through FY14 (plus current $12M = $160M)
- LDSD dependent on NASA OCT receiving funding in FY12
  - Not a given due to propensity of Congress to operate the country on continuing resolutions — OCT not funded in current operating budget